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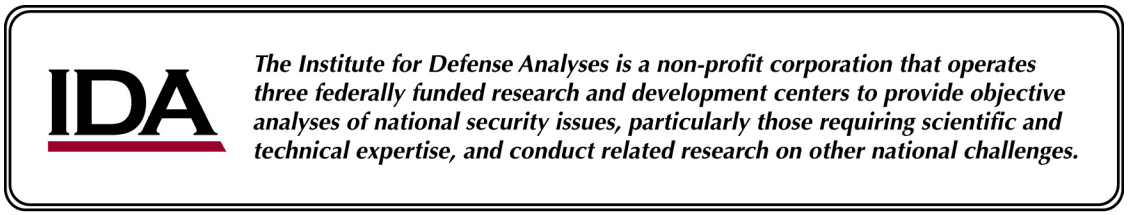


**About This Publication**

This work was conducted by the Institute for Defense Analyses (IDA) under contract HQ0034-14-D-0001, Project AM-2-1528, "Assessment of Traditional and Emerging Approaches to the Detection and Classification of Surface and Buried Unexploded Ordnance (UXO)," for the Director, Environmental Security Technology Certification Program (ESTCP) and Strategic Environmental Research and Development Program (SERDP), under the Deputy Under Secretary of Defense, Installations and Environment. The views, opinions, and findings should not be construed as representing the official position of either the Department of Defense or the sponsoring organization.

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# UXO Live Site Classification Demonstrations: A Retrospective Summary

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## Introduction

- **Unexploded Ordnance (UXO)** may contaminate 1400 sites in over 10M acres in the United States*:
  - UXO can bury in the ground and become difficult to distinguish from metallic clutter using traditional detection methods
  - As recently as the early 2000s, 75% of remediation costs were spent on false alarms – excavating objects that turned out to be clutter

* Defense Science Board (DSB). *Report of the Defense Science Board Task Force of Unexploded Ordnance.* December 2003

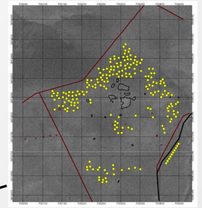
UXO *VS.* Clutter

- The Environmental Security Technology Certification Program (ESTCP) has sponsored the development of **advanced geophysical instruments and software** to rank the likelihood that a buried object is UXO:
  - Objects with a low UXO likelihood can be classified as clutter and left unexcavated, reducing remediation costs
  - Remediation resources can then be directed towards excavating all other objects, allowing more land to be cleared for the same price
- ESTCP has sponsored a series of **demonstrations** to assess the capability of advanced geophysical classification technologies for safely remediating land of UXO while reducing remediation costs

## Methods

For each demonstration:

- ESTCP emplaced inert and surrogate UXO in the ground to increase the number of **Targets of Interest (TOI):**
  - TOI = UXO, inert and surrogate munitions, seeds, and any other objects for which the site team agrees that removal is required
- Thousands of clutter objects were already native to the site



**TOI emplacement plan for the Camp San Luis Obispo (SLO) demonstration:**
- Site Boundary
- Road or Rocks
- TOI emplacement

**Collecting data with the Time-domain ElectroMagnetic Towed Array Detection System (TEMTADS)**

**Ranked Anomaly List**

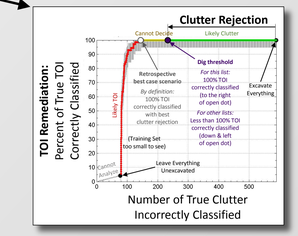
| Target ID | Category | Dig Decision |
|---|---|---|
| XX-2003 | Cannot Analyze | Excavate |
| XX-2013 | Cannot Analyze | Excavate |
| XX-2030 | Cannot Analyze | Excavate |
| ... | ... | ... |
| XX-2323 | Training Set | Excavate |
| XX-2338 | Training Set | Excavate |
| ... | ... | ... |
| XX-2413 | Likely TOI | Excavate |
| XX-2504 | Likely TOI | Excavate |
| XX-2665 | Likely TOI | Excavate |
| XX-2903 | Likely TOI | Excavate |
| XX-2278 | Likely TOI | Excavate |
| ... | ... | ... |
| XX-2677 | Cannot Decide | Excavate |
| XX-2364 | Cannot Decide | Excavate |
| XX-2616 | Cannot Decide | Excavate |
| ... | ... | ... |
| XX-2674 | Likely Clutter | Leave Unexcavated |
| XX-2058 | Likely Clutter | Leave Unexcavated |
| XX-2274 | Likely Clutter | Leave Unexcavated |
| XX-2054 | Likely Clutter | Leave Unexcavated |
| XX-2541 | Likely Clutter | Leave Unexcavated |
| ... | ... | ... |

TOI Likelihood Rank

Dig Threshold

- Demonstrators collected data using **advanced instruments** and processed the data using **advanced software** to produce a ranked anomaly list
- Each **ranked anomaly list** consisted of an ordered set of locations detected at the site, ranked by their likelihood of containing a buried TOI
- Demonstrators selected a **dig threshold** to apply to each ranked anomaly list

**ROC Curve**




- ESTCP excavated all detected locations to construct **ground truth**
- The Institute for Defense Analyses (IDA) compared each list to ground truth and created a **Receiver-Operating Characteristic (ROC) curve** to score the list's performance

## Results

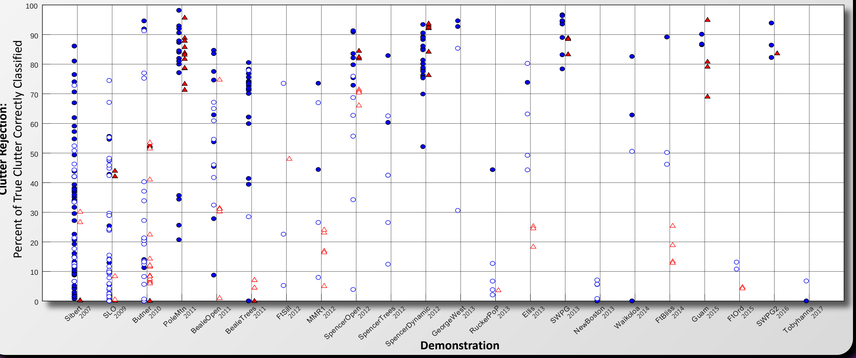
**UXO Live Site Demonstrations, FY2007 - FY2017**

| Year | Demonstration | Location | Number of intermediate and final lists | TOI types (description or caliber) | Instruments |
|---|---|---|---|---|---|
| 2007 | Sibert | Camp Sibert, AL | 42 | 4.2in | Berkeley UXO Discriminator (BUD), EM61-Mk2 Cart, EM63 (cued), GEM-3 (cued), Multi-Sensor Towed Array Detection System (MTADS) - EM61-Mk2/GEM-3/mag |
| 2009 | SLO | Camp San Luis Obispo, CA | 59 | 37mm, 60mm, 81mm, 2.36in, 3in, 4.2in, 5in | BUD, EM61-Mk2 Cart, MTADS - EM61-Mk2/mag, Man-portable Simultaneous magnetometer and ElectroMagnetic System (MSEMS), MetalMapper, Time-domain ElectroMagnetic Towed Array Detection System (TEMTADS) 5x5 |
| 2010 | Butner | Camp Butner, NC | 54 | 37mm, M48 fuze, 105mm | EM61-Mk2 Cart, MetalMapper, TEMTADS 5x5 |
| 2011 | PoleMtn | Pole Mountain, WY | 36 | small Industry Standard Object (ISO), 37mm, 57mm, 60mm, 75mm, 3in | EM61-Mk2 Cart, MetalMapper |
| | Beale | Camp Beale, CA | 95 | small ISO, 37mm, 60mm, 81mm, 105mm | BUD, EM61-Mk2 Cart, MetalMapper, Man Portable Vector (MPV), TEMTADS 2x2 |
| 2012 | FtSill | Fort Sill, OK | 9 | signal flare, RA/RI pipe, Laws rocket motor, grenade, rifle grenade, practice grenade, flare canister, small ISO, 37mm, 40mm, 2.36in, 3.5in | MetalMapper |
| | MMR1 | Massachusetts Military Reservation, MA | 24 | parachute flare, illumination round, smoke canister, cartridge, 37mm, medium ISO, 60mm, 2.5in, 75mm, 81mm, 105mm, 4.2in, 155mm, 8in | MetalMapper, TEMTADS 2x2 |
| | Spencer | Camp Spencer, TN | 75 | small ISO, 37mm, medium ISO, 60mm, 75mm, 3in, 105mm, 155mm | MetalMapper, MPV, TEMTADS 2x2 and 5x5 |
| 2013 | GeorgeWest | Camp George West, CO | 5 | medium ISO, 75mm | MPV |
| | RuckerPoP | Fort Rucker, AL | 32 | small ISO, hand grenade, rifle grenade, 2.36in, 2.36in motor, 3.5in motor, one 2.36in motor & one 3.5in motor, two 2.36in motors, three 2.36in motors, three 2.36in motors & one 3.5in motor, one 2.36in & 118 2.36in motors | MetalMapper, TEMTADS 2x2 and 5x5 |
| | Ellis | Camp Ellis, IL | 18 | small ISO, grenade, hand grenade, rifle grenade, 2.36in | MetalMapper, TEMTADS 2x2 |
| | SWPG | Southwestern Proving Ground, AR | 21 | 20mm, small ISO, 37mm, 40mm, medium ISO, 75mm, 90mm, 105mm | MetalMapper, TEMTADS 2x2 |
| | NewBoston | New Boston Air Force Station, NH | 9 | 1/2in x 2in pipe, 1/2in x 3in pipe, 20mm, two 20mm, small ISO, scar rocket, 3lb2 practice bomb, M103 bomb nose fuze, 100lb bomb, M1 practice bomb | MPV, TEMTADS 2x2 |
| 2014 | Waikoloa | Waikoloa, HI | 9 | small ISO, 37mm, medium ISO, 60mm, 81mm, TOI frag | MetalMapper, MPV, MPV3D |
| | FtBliss | Castner Range in Fort Bliss, TX | 12 | 25mm, small ISO, 37mm, 105mm | TEMTADS 2x2 |
| 2015 | Guam | Andersen Air Force Base, Guam | 14 | small ISO, 37mm | TEMTADS 2x2 |
| | FtOrd | Fort Ord, CA | 4 | 20mm, 35mm, small ISO, 37mm, 40mm, 57mm, medium ISO, 60mm, 75mm, 81mm, large ISO, 105mm, 4.2in, 155mm | MetalMapper |
| 2016 | SWPG2 | Southwestern Proving Ground, AR | 8 | 20mm, small ISO, 37mm, 40mm, 57mm, 75mm, 90mm | One-Pass Time-domain ElectroMagnetic induction Array (OPTEMA), TEMTADS 2x2 |
| 2017 | Tobyhanna | Tobyhanna Army Depot, PA | 2 | small ISO, medium ISO, 75mm | MPV |

From FY2007 – FY2017, IDA scored 538 lists created by 22 organizations using 11 instruments in 19 demonstrations

**Performance of Every Final List from Every Demonstration, FY2007 - FY2017**

- *IF* 100% of TOI were correctly classified at the **dig threshold**, *THEN* plot **clutter rejection** at the **dig threshold**, with **filled markers** indicating who created the list:
  - Technology Developer
  - Production-Level Remediation Company
- *ELSE IF* less than 100% of TOI were correctly classified at the **dig threshold**, *THEN* plot **clutter rejection** for the retrospective best case scenario, with **open markers** indicating who created the list:
  - Technology Developer
  - Production-Level Remediation Company




## Discussion

- By design, later demonstrations typically included smaller TOIs:
  - Rule of thumb: the smaller the TOI, the more difficult the demonstration
- Overall, demonstration results typically improved with chronological order:
  - **By 2011, most organizations at most sites could correctly classify 100% TOI while rejecting more than 70% clutter**
  - On other sites, advanced geophysical classification demonstrated utility for more directed goals, *e.g.*:
    - FtOrd: large, shallow munitions could be correctly classified
    - MMR1: large munitions with unexpended explosive material could be correctly classified
- Improvements in classification results over time were likely due to advances in instruments, software, and processes for quality control and quality assurance
- Advanced geophysical classification technology now has the capability to focus remediation efforts on the excavation of explosive hazards while reducing the costly and unnecessary excavation of non-explosive clutter

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14. ABSTRACT

This poster highlights a series of increasingly challenging live-site demonstrations, sponsored by the Environmental Security Technology Certification Program, to explore the capability of advanced geophysical classification for remediating land of unexploded ordnance.

15. SUBJECT TERMS

Environmental Security Technology Certification Program (ESTCP); live-site demonstration; number of unnecessary excavations; probability of correct classification; Strategic Environmental Research and Development Program (SERDP); targets of interest (TOI); unexploded ordnance (UXO)

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